Introduction

Chapter Background

Science and engineering (S&E), and the technological developments that emerge from S&E activities, enable high-wage nations like the United States to compete alongside low-wage countries in today's increasingly global marketplace. Nearly a universally accepted wisdom today, the importance of S&E activities to the Nation's economic well-being was emphasized 50 years ago in *Science and Public Policy*, a report prepared for then-President Harry S Truman under the guidance of John Steelman (1947). (See chapter 1.) It stated, "Only through research and more research can we provide the basis for an expanding economy, and continued high employment levels." In the years following World War II, U.S. industry became an integral part of the research enterprise. Not just as a performer of R&D, U.S. industry became the main conduit for diffusing and commercializing investments in S&T made by industry, academia, and government. The *Science and Engineering Indicators 2000* continues to acknowledge the important role played by industry. Contained within this chapter are indicators or proxies that identify trends and provide measurements of industry's part in the S&T enterprise and, whenever possible, place U.S. activity and standing in the more science-based industries in a global context.

The highly competitive global marketplace facing the Nation today is yet another condition predicted 50 years ago in the Steelman report. Steelman (1947) warned of the reemergence of war-torn economies in Europe and Asia and the emergence of a new cadre of nation traders that would "...confront us with competition from other national economies of a sort we have not hitherto had to meet." If a nation's competitiveness is judged by its ability to produce goods that find demand in the international marketplace while simultaneously maintaining—if not improving—the standard of living of its citizens (OECD 1996), then the United States appears to have met the challenges outlined in the Steelman report. Now some 50 years after that report was written, the U.S. economy ranks as the world's largest, and Americans enjoy one of the world's higher standards of living—although many other parts of the world are closing the gap. (See figure 7-1 and appendix tables 7-1, 7-2, and 7-3.)

Chapter Organization

This chapter begins with a review of the market competitiveness of industries that rely heavily on R&D; these are often referred to as high-technology industries.[1] The importance of high-technology industries is linked to their high R&D spending and performance, which produce innovations that spill over into other economic sectors. Additionally, these industries help train new scientists, engineers, and other technical personnel. (See Nadiri 1993 and Tyson 1992.) The market competitiveness of a nation's technological advances, as embodied in new products and processes associated with these industries, can also serve as an indicator of the effectiveness of that country's S&T enterprise. The marketplace provides a relevant economic evaluation of a country's use of S&T.

U.S. high-technology industry competitiveness is assessed through an examination of market share trends worldwide, at home, and in various regions of the world. New data on royalties and fees generated from U.S. imports and exports of technological know-how are used to gauge U.S. competitiveness when technological know-how is sold or rented as intangible (intellectual) property.

The chapter explores several leading indicators of technology development (1) via an examination of changing emphases in industrial R&D among the major industrial countries and (2) through an extensive analysis of patenting trends. New information on international patenting trends of U.S. foreign inventors in several important technologies is presented.

The chapter concludes with a presentation of information on trends in venture capital disbursements. Venture capital is an important source of funds used in the formation and expansion of small high-technology companies. This section examines venture capital disbursements by stage of financing and by technology area in the United States.

U.S. Technology in the Marketplace

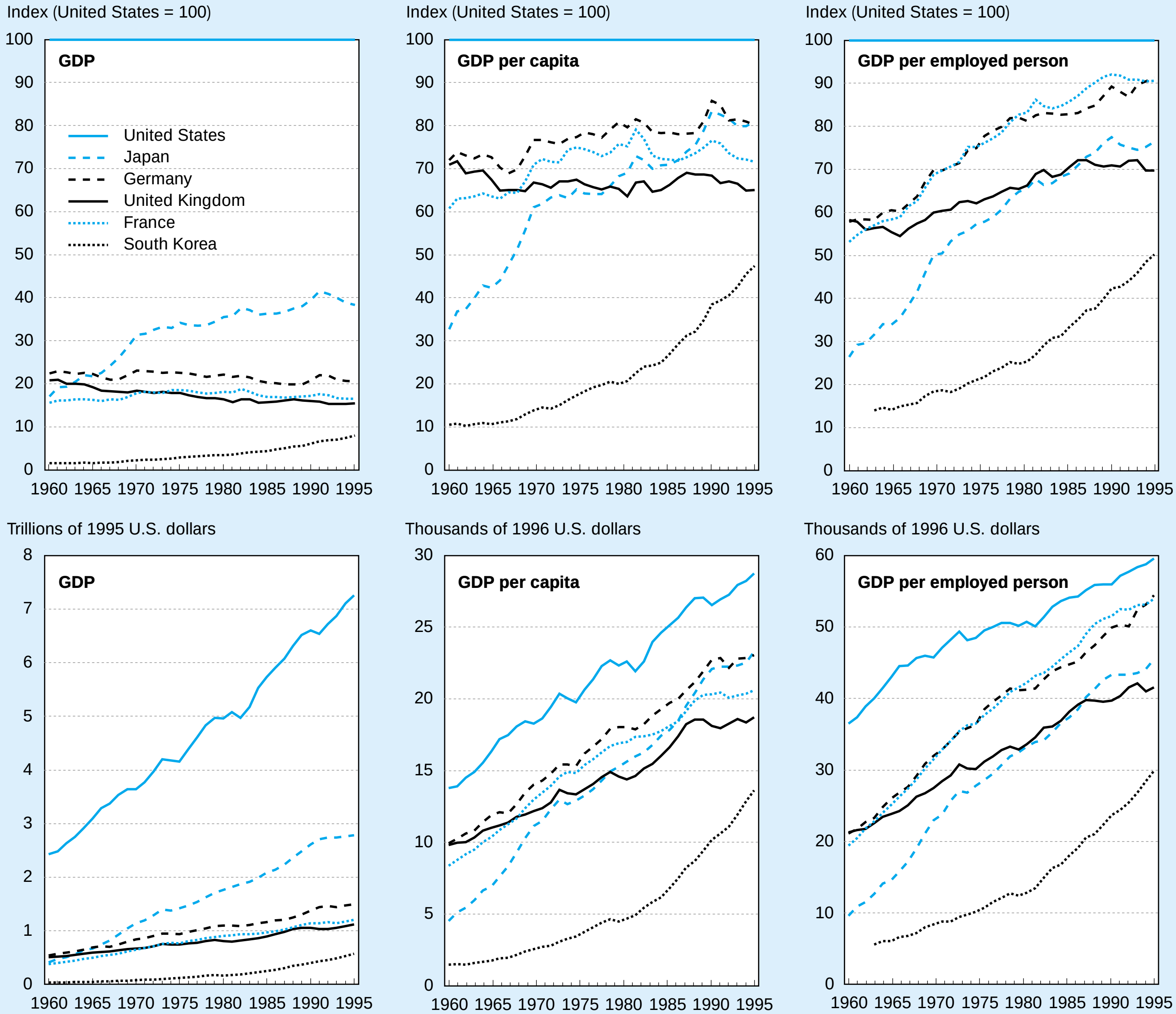
Most countries in the world acknowledge a symbiotic relationship between national investments in S&T and competitiveness in the marketplace: S&T support business competitiveness in international trade, and commercial success in the global marketplace provides the resources needed to support new S&T. Consequently, the health of the nation's economy becomes a performance measure for the national investment in R&D and in S&E.

This section discusses U.S. "competitiveness," broadly defined here as the ability of U.S. firms to sell products in the international marketplace. A great deal of attention is given to science-based industries producing products that embody above-average levels of R&D in their development (hereafter referred to as *high-technology industries*). OECD currently identifies four industries as high-technology based on their high R&D intensities: aerospace, computers and office machinery, electronics-communications, and pharmaceuticals.[2]

[1]In this chapter, high-technology industries are identified using R&D intensities calculated by the OECD. There is no single preferred methodology for identifying high-technology industries. The identification of those industries considered to be high-technology has generally relied on a calculation comparing R&D intensities. R&D intensity, in turn, has typically been determined by comparing industry R&D expenditures and/or numbers of technical people employed (such as scientists, engineers, and technicians) to industry value added or the total value of its shipments.

[2]In designating these high-technology industries, the OECD took into account both direct and indirect R&D intensities for 10 countries: the United States, Japan, Germany, France, the United Kingdom, Canada, Italy, the Netherlands, Denmark and Australia. Direct intensities were calculated by the ratio of R&D expenditure to output (production) in 22 industrial sectors. Each sector was given a weight according to its share in the total output of the 10 countries using purchasing power parities as exchange rates. Indirect intensity calculations were made using technical coefficients of industries

Figure 7-1.
International economic comparisons



NOTE: Country GDPs were determined with 1993 purchasing power parities using the Elteto-Köves-Szulc (EKS) aggregation method and 1996 U.S. dollars (1995 U.S. dollars for aggregate GDP).

See appendix tables 7-1, 7-2, and 7-3.

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There are several reasons why high-technology industries are important to nations:

- ♦ High-technology firms are associated with innovation. Firms that innovate tend to gain market share, create new product markets, and/or use resources more productively (NRC, Hamburg Institute for Economic Research, and Kiel Institute for World Economics 1996; Tassey 1995).
- ♦ High-technology firms are associated with high value added production and success in foreign markets which helps to support higher compensation to the workers they employ (Tyson 1992).
- ♦ Industrial R&D performed by high-technology industries has other spillover effects. These effects benefit other com-

on the basis of input-output matrices. The OECD then assumed that for a given type of input and for all groups of products, the proportions of R&D expenditure embodied in value added remained constant. The input-output coefficients were then multiplied by the direct R&D intensities. For further details concerning the methodology used, see OECD (1993).

mercial sectors by generating new products and processes that can often lead to productivity gains, business expansions, and the creation of high-wage jobs (Nadiri 1993, Tyson 1992, and Mansfield 1991).

The Importance of High-Technology Industries

The global market for high-technology goods is growing at a faster rate than that for other manufactured goods, and economic activity in high-technology industries is driving national economic growth around the world.[3] During the 18-year period examined (1980–97), high-technology production grew at an inflation-adjusted average annual rate of nearly 6.2 percent compared with a rate of 2.7 percent for other manufactured goods.[4] Global economic activity was especially strong at the end of the period (1994–97), when high-technology industry output grew at more than 11 percent per year—more than four times the rate of growth for all other manufacturing industries. (See appendix table 7-4.) Output by the four high-technology industries—those identified as being the most research intensive—represented 7.1 percent of global production of all manufactured goods in 1980; by 1997, this output represented 11.9 percent.

During the 1980s, the United States and other high-wage countries increasingly moved resources toward the manufacture of higher-value, technology-intensive goods often referred to as high-technology manufactures. In 1989, U.S. high-technology manufactures represented nearly 11 percent of total U.S. production of manufactured output, up from 9.6 percent in 1980. High-technology manufactures also accounted for growing shares of total production for European nations, although to a lesser degree than that seen in the United States. The one exception was the United Kingdom where the transition to high technology during the 1980s was similar to that in the United States. High-technology manufactures represented just 9 percent of the United Kingdom's total manufacturing output in 1980 and nearly 11 percent by 1989. The Japanese economy led all other major industrial countries in its concentration on high-technology industries during the 1980s. In 1980, high-technology manufactures accounted for about 8 percent of total Japanese production, approached 11 percent in 1984, and then increased to 11.6 percent in 1989. (See the sidebar, "International Activity in High-Technology Service Industries.")

Data for the 1990s show an increased emphasis on high-technology manufactures among the major industrial countries. (See figure 7-4.) In 1997, high-technology manufactures were estimated to represent 15.7 percent of manufacturing output in Japan, 14.7 percent in the United States, 11.7 percent in the United Kingdom, and 8.3 percent each in France and Germany. Two other Asian countries, China and South Korea, typify how important R&D-intensive industries have become to the newly industrialized economies. In 1980, high-technology manufactures accounted for less than 7 percent of China's total manufacturing output; this proportion jumped

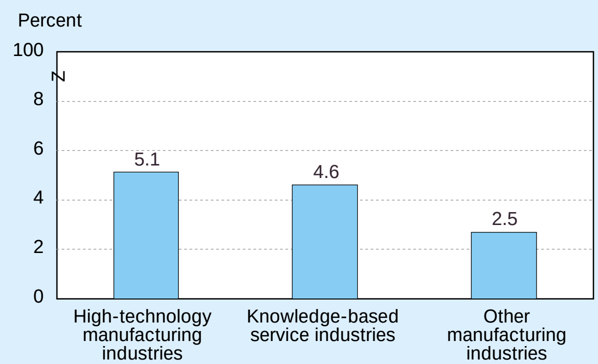
[3]This section is based on data reported by the WEFA Group in its Global Industry Model database. This database provides production data for 68 countries and accounts for more than 97 percent of global economic activity.

[4]Knowledge-based service sector industries grew at an average annual inflation-adjusted rate of 4.6 percent during this period.

International Activity in High-Technology Service Industries

For several decades, revenues generated by U.S. service sector industries have grown faster than revenues generated by the Nation's manufacturing industries. Data collected by the U.S. Department of Commerce show that the U.S. service sector's share of the U.S. GDP grew from 49 percent in 1959 to 64 percent in 1997 (See appendix table 9-4.) Service sector growth has in large part been fueled by industries often described as "knowledge-based" industries—those incorporating science, engineering, and technology in the services being provided or in the delivery of those services. Prominent examples of these "knowledge-based" industries include communication services, financial services, business services (including computer software–related services), educational services, and health services. These industries have been growing nearly as fast as the high-technology manufacturing sector discussed earlier. (See figure 7-2.)

Figure 7-2.
Average annual rates of growth in three U.S. economic sectors: 1980–97



See appendix tables 7-4 and 7-5.

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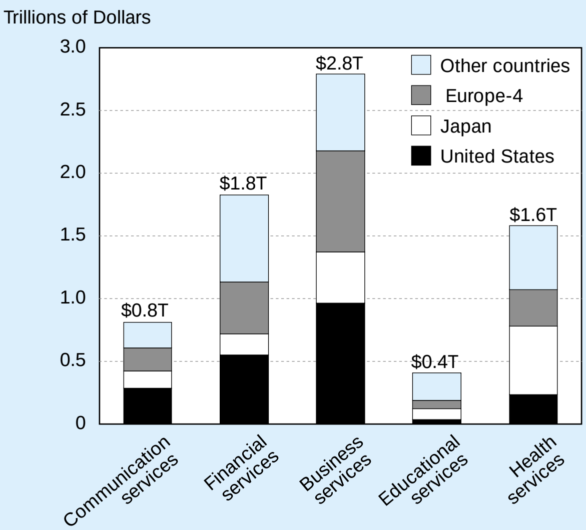
New data provided by the WEFA Group tracks overall revenues earned by these industries in 64 countries.* Similar to the value of production or data on total shipments previously discussed for high-technology manu-

*Unlike that for manufacturing industries, national data tracking activity in many of the hot new service sectors are limited in the level of industry disaggregation that is available and the types of activity for which national data are collected.

facturing industries, these data permit an examination of the global U.S. position in each of the service sector industries. (See figure 7-3 and appendix table 7-5.)

Combined worldwide sales in these five service sector industries exceeded $7.4 trillion in 1997, up from $5.8 trillion in 1990 and $3.4 trillion in 1980 (1997 dollars). The United States was the leading national provider of high-technology services, responsible for more than 28–30 percent of total world service revenues during the 1980s and for about 27 percent of revenues during the 1990–97 period.

Figure 7-3.
Global activity in five knowledge-based service industries in 1997



NOTE: Europe-4 refers to the four largest European economies: France, Germany, Italy, and the United Kingdom.

See appendix table 7-5. *Science & Engineering Indicators – 2000*

Business services, which include computer and data processing services, research and engineering services, and other business services, is the largest of the five-industry service sector and accounted for nearly 38 percent of revenues in 1997. The U.S. business service industry is the largest in the world with 34.4 percent of industry revenues in 1997. Japan was second at 14.7 percent, followed by Germany with 10.0 percent and France at 9.8 percent. Unfortunately, data on individual business services by country are not available.

Services provided by financial institutions represent the second largest of the five service industries examined, and accounted for nearly 25 percent of revenues in 1997. Among the three largest advanced nations, the U.S. financial services industry is the largest with 30.0 percent of world industry revenues in 1997. Japan was again second at 9.3 percent followed by Germany at 6.6 percent.

Communications services, which include telecommunications and broadcast services, represent the third largest of the five service industries examined and accounted for 10.9 percent of revenues in 1997. In what many consider the most technology-driving of the service industries, the U.S. industry has the most dominant position. In 1997, U.S. communications firms generated revenues that accounted for 35.2 percent of world revenues, more than twice the share held by Japanese firms, and nearly five times that held by German firms.

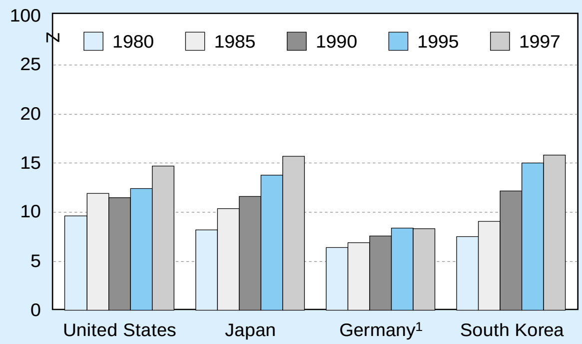
More than the first three, the remaining two knowledge-based service industries—health services and educational services—operate on the edge of government services. Health services industry data examined here track services provided by private hospitals, doctors, and miscellaneous medical services. Educational services include commercial education and library services. In both health and education services, Japan's industries are the largest in the world and lead the next largest national industry—that in the United States—by large margins. Japan's share of world revenues in the health services industry was 34.6 percent in 1997—more than twice the share for the U.S. health services industry. Of the four largest European economies, Italy had the largest health service industry. In educational services, Japan's leading share of the world revenues was lower than that in health services—21.7 percent versus 34.6 percent—but this leading share was two and a half times greater than the second largest national industry in the United States. Italy once again had the next largest share, 4.8 percent, although the other large European economies had educational services nearly as big. Educational services represented the smallest of the five knowledge-based service industries with about one-seventh of the revenues generated by the business services industry worldwide.

to 11.6 percent in 1989 and reached 14.8 percent in 1997—about the same as in the United States. In 1997, high-technology manufacturing in South Korea accounted for about the same percentage of total output as in Japan (15.8 percent) and almost twice the percentage of total manufacturing output in France and Germany.

Share of World Markets

Throughout the 1980s, the United States was the leading producer of high-technology products, and was responsible for more than one-third of total world production from 1980 to 1987, and for about 30 percent of world production for the rest of the decade. U.S. world market share held fairly steady

Figure 7-4.
High-technology industries' share of total manufacturing output



See appendix table 7-4. *Science & Engineering Indicators – 2000*

[1]German data are for West Germany only.

during much of the 1990s and moved up slightly in both 1996 and 1997. (See figure 7-5.) In 1997, production by U.S. high-technology industry accounted for nearly 32 percent of world high-technology production.

While U.S. high-technology industry struggled to maintain market share during the 1980s, the Asian global market share in high-technology industries followed a path of steady gains. In 1989, Japan accounted for 24 percent of the world's production of high-technology products, moving up 4 percentage points since 1980. Japan continued to gain market share through 1991. Since then, however, Japan's market share has dropped steadily, falling to under 22 percent of world production in 1997 after accounting for nearly 26 percent in 1991.

By comparison, many European nations' share of world high-technology production is much lower. Germany produced about 8 percent of world high-technology production in 1980, about 7 percent in 1989, and less than 6 percent in 1997. Shares for the United Kingdom declined in a similar fashion. In 1980, United Kingdom's high-technology industry produced about 7 percent of world output, it dropped to about 6 percent in 1989, and to 4.4 percent by 1997. French high-technology industry never accounted for more than 4.5 percent of world high-technology output during the period examined, and its shares trended downward to about 3 percent by 1997. Italy's shares were the lowest among the four large European economies, ranging from a high of about 2.5 percent of world high-technology production in 1980 to a low of about 1 percent in 1997.

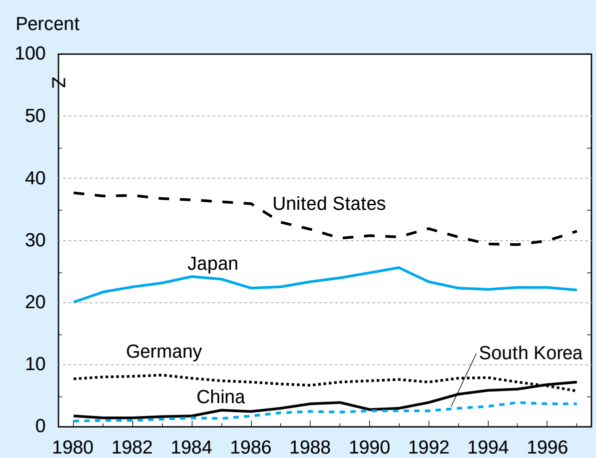
Developing Asian nations made the most dramatic gains since 1980. China's market share doubled during the 1980s, moving from 1.8 percent in 1980 to 3.9 in 1989, and is on track to double again during the 1990s with its latest share reaching 7.2 in 1997. Production by China's high-technology industries in 1997 was larger than any European nation. Like China, high-technology industries in South Korea quickly gained market during the 1980s and expanded that market share in the 1990s. Starting with less than 1 percent in 1980, output by high-technology industries in South Korea accounted for 2.4 percent of world output in 1989 and 3.7 percent by 1997. Compared with high-technology production in the four largest European countries, South Korea's share of world production in 1997 was smaller than that in either Germany or United Kingdom, but larger than that produced by high-technology industries in both France and Italy.

Global Competitiveness of Individual Industries

In each of the four industries that make up the high-technology group, the United States maintained strong, if not leading, market positions during the 18-year period examined. Yet competitive pressures from a growing cadre of high-technology–producing nations contributed to a decline in global market share for two U.S. high-technology industries during the 1980s: aerospace and communications equipment. Since then, both of these industries—in particular, communications equipment—reversed their downward trends and gained market share in the mid- to late 1990s. (See figure 7-6.)

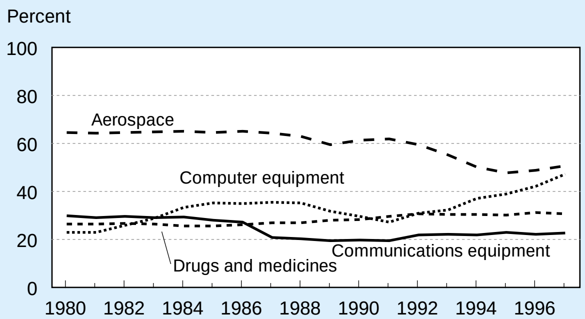
The U.S. aerospace industry, the Nation's strongest high-technology industry in terms of world market share, was the one high-technology industry to lose market share in the 1980s and again in the 1990s. For much of the 1980s, the U.S. aerospace industry supplied about two-thirds of world demand. By the late 1980s, the U.S. share of the world aerospace market began an erratic decline and dropped to under 60 percent by 1989. The U.S. aerospace industry maintained this market share up until 1993 when market share, once again, began to slip, falling to its lowest level for the period (under 48 percent) in 1995. The U.S. share recovered somewhat during the following two years reaching 51 percent of the world market in 1997. While European aerospace industries made some gains during this time, China's industry recorded large gains in global market share beginning in 1992. In 1980, China

Figure 7-5.
Country share of global high-technology output



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Figure 7-6.
U.S. global output share, by high-technology industry



See appendix table 7-4. *Science & Engineering Indicators – 2000*

supplied about 2.9 percent of world aircraft shipments; by 1997, its share had increased to nearly 16 percent. (See figure 7-7.) [5]

As previously noted, two U.S. high-technology industries lost market share during the late 1980s and then reversed that trend during the 1990s. By 1997, the United States was the number one supplier of computer equipment in the world and the second leading supplier of communications equipment behind Japan.

Of the four high-technology industries, only the U.S. aerospace and U.S. pharmaceutical industries managed to retain their number one rankings throughout the 18-year period. Of these two, only the U.S. pharmaceutical industry had a larger share of the global market in 1997 than in 1980.

The United States is considered a large, open market. These characteristics benefit U.S. high-technology producers in two important ways. First, supplying a market with many domestic consumers provides scale effects to U.S. producers in the form of potentially large rewards for the production of new ideas and innovations (Romer 1996). Second, the openness of the U.S. market to foreign-made technologies pressures U.S. producers to be inventive and to move toward more rapid innovation to maintain domestic market share.

This discussion of world market shares shows that U.S. producers are leading suppliers of high-technology products to the global market. That evaluation incorporates U.S. sales to domestic, as well as to foreign customers. In the next sections, these two markets are examined separately.

Exports by High-Technology Industries

While U.S. producers reaped many benefits from having the world's largest home market (as measured by GDP), mounting trade deficits highlight the need to also serve demand in foreign markets. U.S. high-technology industries have traditionally been more successful exporters than other U.S. industries. Consequently, high-technology industries have attracted considerable attention from policymakers as they seek ways to return the United States to a more balanced trade position.

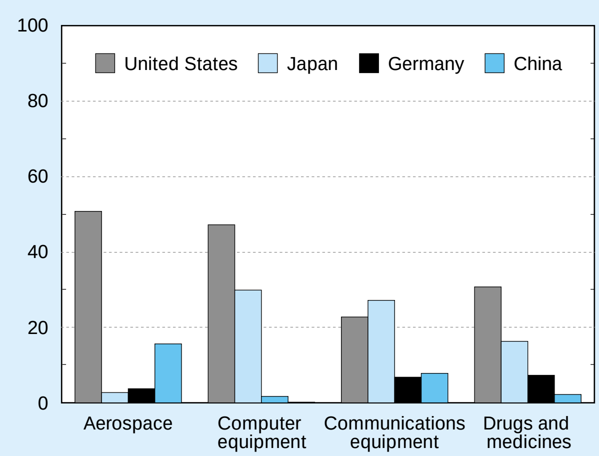
Foreign Markets

Despite its domestic focus, the United States has been an important supplier of manufactured products in foreign markets throughout the 1980–97 period. From 1994 to 1997, the United States was the leading nation exporter of manufactured goods and accounted for about 12 percent of world exports.

U.S. high-technology industries have contributed to this strong export performance of the nation's manufacturing industries. (See figure 7-8.) During the same 18-year period, U.S. high-technology industries accounted for between 17 and 25 percent of world high-technology exports—which is at times twice the level achieved by all U.S. manufacturing industries. In 1997, the latest year for which data are available, exports by U.S. high-technology industries accounted for 18.1 percent of world high-technology exports. Japan was second, accounting for 9.1 percent, followed by the United Kingdom with 8.3 percent.

The drop in U.S. share over the 18-year period is in part the result of the emergence of high-technology industries in newly industrialized economies, especially within Asia. Singapore and South Korea are two examples. In 1980, high-technology industries in Singapore and South Korea accounted for about 2.6 percent and 1.5 percent of world high-technology exports, respectively. Both nations' market shares doubled by the late 1980s. The latest data for 1997 show Singapore's share reaching 8.0 percent and South Korea's share reaching 5.4 percent.

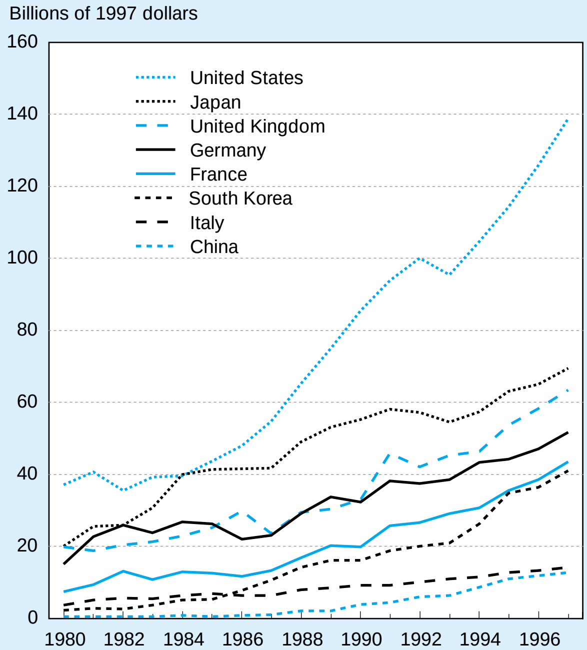
Figure 7-7.
Global output share, by selected country and high-technology industry: 1997



See appendix table 7-4. *Science & Engineering Indicators – 2000*

[5]Industry experts in the United States contacted to confirm such a large China presence in the market for aerospace products suggest that China's production may be more heavily concentrated in satellite launch equipment and noncommercial production than in commercial aircraft.

Figure 7-8.
High-technology exports



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Industry Comparisons

Throughout the 18-year period, individual U.S. high-technology industries either led in exports or were second to the leader in each of the four industries included in the high-technology grouping. The most current data (1997) show the United States as the export leader in three industries and third in just one—drugs and medicines. (See figure 7-9.)

U.S. industries producing aerospace, computers, and drugs and medicines all accounted for smaller export shares in 1997 than in 1980. The communications equipment industry was the sole U.S. high-technology industry to improve its share of world exports during the period. By comparison, the share of world exports held by Japan's communications equipment industry dropped steadily after 1985—eventually falling to 12.3 percent by 1997 from a high of 33.6 percent just 12 years earlier. Once again the newly industrialized economies of Asia demonstrated an ability to produce high-technology goods to world-class standards and were rewarded with great success in selling to foreign markets. In 1997, South Korea supplied 7.8 percent of world communications product exports, up from just 2.9 percent in 1980. Singapore supplied 9.9 percent of world computer equipment exports in 1997, up from 4.8 percent in 1980. Other Asian newly industrialized economies have demonstrated strong capabilities in those two high-technology industries.

Competition in the Home Market

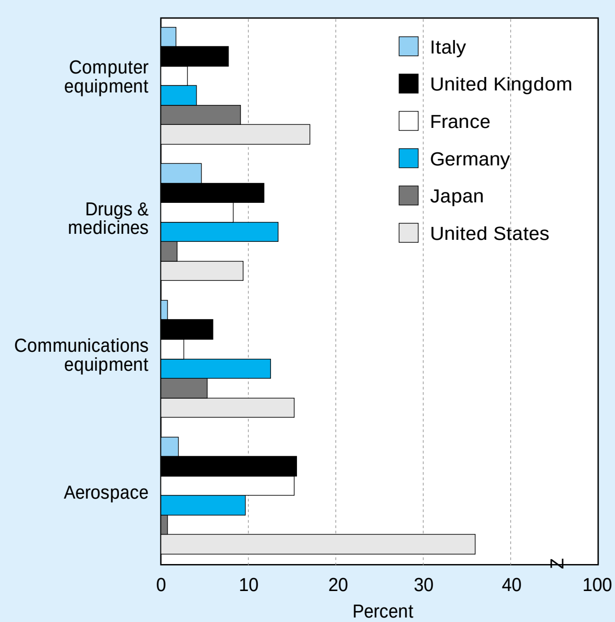
A country's home market is often thought of as the natural destination for the goods and services produced by domestic firms. For obvious reasons—including proximity to the customer and common language, customs, and currency—marketing at home is easier than marketing abroad.

With trade barriers falling and the number of foreign firms able to produce goods to world standards rising, however, product origin may be only one factor among many influencing the consumer's choice between competing products. Price, quality, and product performance often become equally or more important determinants guiding product selection. Thus, in the absence of trade barriers, the intensity of competition faced by domestic producers in their home market can approach—and, in some markets, may even exceed—the level of competition faced in foreign markets. Explanations for U.S. competitiveness in foreign markets may be found in the two dynamics of the U.S. market: the existence of tremendous domestic demand for the latest advanced technology products and the degree of world-class competition that continually pressures U.S. industry toward innovation and discovery.

National Demand for High-Technology Products

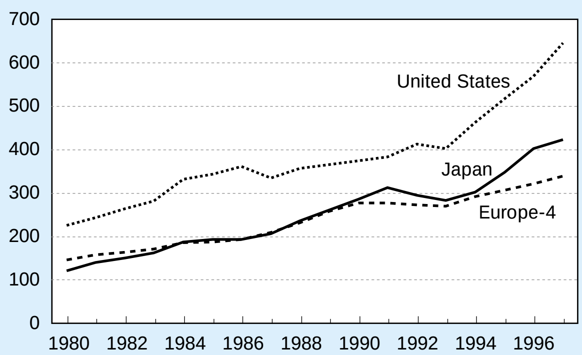
Demand for high-technology products in the United States far exceeds that in any other single country and is larger than the combined markets of the four largest European nations: Germany, the United Kingdom, France, and Italy. (See figure 7-10.) This was consistently the case for the entire 1980–97 period. Japan was the second largest market for high-tech-

Figure 7-9.
Export market share in high-technology industries: 1997



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Figure 7-10.
National consumption of high-technology products



NOTE: Europe-4 refers to the four largest European economies: Germany, France, the United Kingdom, and Italy.

See appendix table 7-4. *Science & Engineering Indicators – 2000*

nology products in the world, although its share of world consumption has generally declined since 1991. China again stands out. In 1980, China consumed less than 2 percent of world high-technology output—its demand doubled by the end of the decade and doubled again by 1997. The latest annual data (1997) show China's economy as the world's second largest consumer of aerospace products, trailing only the United States, and the fourth largest consuming nation of communications equipment, trailing the United States, Japan, and Germany.

National Producers Supplying the Home Market

Throughout the 1980–97 period, the world's largest market for high-technology products, the United States, was served primarily by domestic producers—yet demand was increasingly met by a growing number of foreign suppliers. (See figure 7-11.) In 1997, U.S. producers supplied about 81.5 percent of the home market for high-technology products (aerospace, computers, communications equipment, and pharmaceuticals). In 1980, however, U.S. producers' share was much higher, about 92.5 percent.

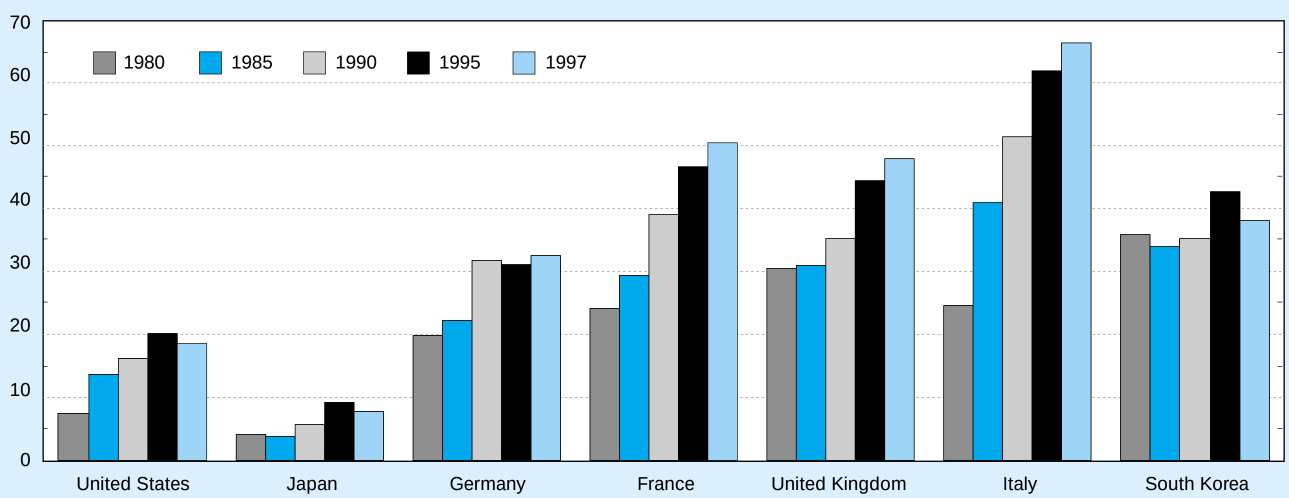
Other countries have experienced similar increased foreign competition in their domestic markets. This is especially true in Europe. A more economically unified European market has had the effect of making Europe an even more attractive market to the rest of the world. Rapidly rising import penetration ratios in the four large European nations during the latter part of the 1980s and throughout much of the 1990s reflect these changing circumstances. These data also highlight greater trade activity in European high-technology markets when compared with product markets for less technology-intensive manufactures.

The Japanese home market, the second largest national market for high-technology products and historically the most self-reliant of the major industrial countries, also increased its purchases of foreign technologies during the 18-year period, albeit slowly. In 1980, imports of high-technology manufactures supplied about 4 percent of Japanese domestic consumption, rising to 5.3 percent in 1989, and then to 7.8 percent by 1997.

U.S. Trade Balance

The U.S. Bureau of the Census has developed a classification system for exports and imports of products that embody new or leading-edge technologies. This classification system allows trade to be examined in 10 major technology areas

Figure 7-11.
Import share of domestic high-technology markets



See appendix table 7-4. *Science & Engineering Indicators – 2000*

that have led to many leading-edge products. These 10 advanced technology areas are as follows:

- *Biotechnology*—The medical and industrial application of advanced genetic research toward the creation of new drugs, hormones, and other therapeutic items for both agricultural and human uses.
- *Life science technologies*—The application of scientific advances (other than biological) to medical science. For example, medical technology advances, such as nuclear resonance imaging, echocardiography, and novel chemistry, coupled with new production techniques for the manufacture of drugs, have led to new products that allow for the control or eradication of disease.
- *Opto-electronics*—The development of electronic products and components that involve emission or detection of light, including optical scanners, optical disk players, solar cells, photosensitive semiconductors, and laser printers.
- *Computers and telecommunications*—The development of products that process increasing volumes of information in shorter periods, including fax machines, telephone switching apparatus, radar apparatus, communications satellites, central processing units, computers, and peripheral units, such as disk drives, control units, modems, and computer software.
- *Electronics*—The development of electronic components (except opto-electronic components), including integrated circuits, multilayer printed circuit boards, and surface-mounted components, such as capacitors and resistors, that result in improved performance and capacity and, in many cases, reduced size.
- *Computer-integrated manufacturing*—The development of products for industrial automation, including robots, numerically controlled machine tools, and automated guided vehicles that allow for greater flexibility in the manufacturing process and reduce the amount of human intervention.
- *Material design*—The development of materials, including semiconductor materials, optical fiber cable, and videodisks, that enhance the application of other advanced technologies.
- *Aerospace*—The development of technologies, such as most new military and civil airplanes, helicopters, spacecraft (with the exception of communications satellites), turbojet aircraft engines, flight simulators, and automatic pilots.
- *Weapons*—The development of technologies with military applications, including guided missiles, bombs, torpedoes, mines, missile and rocket launchers, and some firearms.
- *Nuclear technology*—The development of nuclear production apparatus, including nuclear reactors and parts, isotopic separation equipment, and fuel cartridges. Nuclear medical apparatus is included in life science rather than this category.

To be included in a category, a product must contain a significant amount of one of the leading-edge technologies, and the technology must account for a significant portion of the product's value. Since the characteristics of products the United States exports are likely to be different from the products the nation imports, experts evaluated exports and imports separately.

There is no single preferred methodology for identifying high-technology industries. Generally, this identification has relied on some calculation comparing R&D intensities. R&D intensity, in turn, has typically been determined by comparing industry R&D expenditures and/or numbers of technical people employed (such as scientists, engineers, and technicians) with industry value added or the total value of its shipments. These classification systems suffer from a degree of subjectivity introduced by the assignment of establishments and products to specific industries. The information produced by these R&D-intensity–based classification systems is often distorted by the inclusion of all products produced by the selected high-technology industries, regardless of the level of technology embodied in the product. In contrast, the advanced technology product system of trade data discussed here allows for a highly disaggregated, more focused examination of technology embodied in traded goods. To minimize the impact of subjective classification, the judgments offered by government experts are subsequently reviewed by other experts.

The Importance of Advanced Technology Product Trade to Overall U.S. Trade

U.S. trade in advanced technology products accounted for an increasingly larger share of all U.S. trade (exports plus imports) in merchandise between 1990 and 1998. (See text table 7-1.) Total U.S. trade in merchandise exceeded $1.6 trillion in 1998; $343 billion involved trade in advanced technology products. Trade in advanced technology products accounts for a much larger share of U.S. exports than of imports (28 percent versus 17 percent in 1998) and makes a positive contribution to the overall balance of trade. After several years in which the surplus generated by trade in advanced technology products declined, that changed in 1996. In 1996 and again in 1997, exports of U.S. advanced technology products outpaced imports producing larger surpluses both years. In 1998, the slowdown in Asian economies led to a decline in exports to this region and a reduction in the surplus generated from U.S. trade in advanced technology products. (See figure 7-12 and text table 7-1.)

Technologies Generating a Trade Surplus

During the 1990s, U.S. exports of advanced technology products generally exceeded imports in 8 of 10 technology

Text table 7-1.
U.S. International trade in merchandise
(Billions of U.S. Dollars)

	1990	1991	1992	1993	1994	1994	1996	1997	1998
Total exports (billions of U.S. dollars)	393.0	421.9	447.5	464.8	512.4	575.9	611.5	679.3	670.6
Technology products (percent)	24.1	24.1	23.9	23.3	23.6	24.0	25.3	26.4	27.8
Other merchandise (percent)	75.9	75.9	76.1	76.7	76.4	76.0	74.7	73.6	72.2
Total imports (billions of U.S. dollars)	495.3	488.1	532.4	580.5	663.8	749.4	799.3	877.3	918.8
Technology products (percent)	12.0	13.0	13.5	14.0	14.8	16.7	16.3	16.8	17.1
Other merchandise (percent)	88.0	87.0	86.5	86.0	85.2	83.3	83.7	83.2	82.9
Total trade (billions of U.S. dollars)	888.3	910.0	979.9	1,045.3	1,176.2	1,325.3	1,410.8	1,556.6	1,589.4
Technology products (percent)	17.3	18.1	18.3	18.1	18.6	19.9	20.2	21.0	21.6
Other merchandise (percent)	82.7	81.9	81.7	81.9	81.4	80.1	79.8	79.0	78.4

NOTE: Total trade is the sum of total exports and total imports.

SOURCE: U.S. Bureau of the Census, Foreign Trade Division <<http://www.fedstats.gov>>1999.

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areas.[6] Trade in aerospace technologies consistently produced the largest surpluses for the United States during the 1990s. Those surpluses narrowed in the mid-1990s as competition from Europe's Airbus Industrie challenged U.S. companies' preeminence both at home and in foreign markets. Aerospace technologies generated a net inflow of $25 billion in 1990, and almost $29 billion in 1991 and 1992. Trade balances then declined 13 percent in 1993, 9 percent in 1994, and 14 percent in 1995. Since then, annual trade balances in aerospace technologies have grown each year. In 1998, the U.S. trade in aerospace technologies produced a net inflow of $39 billion, the largest surplus recorded during the 1990–98 period.

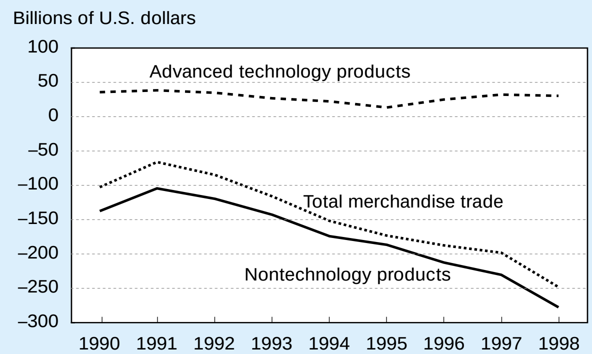
In five other the technology areas, trade is fairly balanced, with only a slight edge to U.S. exports over imports. U.S. trade in biotechnologies, computer integrated manufacturing technologies, material design, weapons, and nuclear technologies each showed surpluses of less than $2 billion in 1998.

Electronics, a technology area where U.S. imports typically exceeded exports, showed a trade surplus in both 1997 and 1998. The annual trade deficit in this technology area grew annually from 1990 to 1994 and then began to narrow. In 1998, U.S. exports of electronics exceeded imports by $4.2 billion. Economic problems in Asia and a stronger U.S. dollar may have lowered the level of electronics products imported from Asia.

Technologies Generating a Trade Deficit

In 1998, trade deficits were recorded in three technology areas—computers and telecommunications, opto-electronics, and life science technologies. The trends for each of these technology areas are quite different. Only opto-electronics

Figure 7-12.
U.S. merchandise trade balance



Calculated from text table 7-1.

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showed trade deficits in each of the nine years examined. U.S. trade in life science technologies had consistently generated annual trade surpluses up until 1998. In 1998, life science exports to Asia fell by 18 percent, and imports from Europe rose sharply, especially from Germany and Ireland. Interestingly, in a technology area where the United States is considered at the forefront—computers and telecommunications—annual U.S. imports have exceeded exports consistently since 1992. Nearly three-quarters of all U.S. imports in this technology area are produced in Asia.[7]

Top Nation Customers, by Technology Area

Japan and Canada are U.S. industry's largest nation customers for U.S. technology products. Each country is the destination for about 11 percent of total U.S. technology exports.

[6] U.S. trade in software products is not a separate ATP category but is included in the ATP category covering computers and telecommunications products. In order to better examine this important technology area, U.S. trade in software products was broken out from the computers and telecommunications category creating an eleventh category.

[7] The Bureau of the Census is not able to identify the degree to which this trade is between affiliated companies.

European countries are also important consumers of U.S. technology products. New markets have developed in several newly industrialized and developing economies, especially in Asia. Technology purchases by these economies now approach levels sold to many of the advanced European countries.

Japan and Canada are among the top three customers across a broad range of U.S. technology products. Japan ranks among the top 3 in 10 of 11 technology areas—Canada in 8. (See figure 7-13.) The United Kingdom is a leading consumer of U.S. products in five areas: opto-electronics, computers and telecommunications, aerospace, weapons and computer software. Although several other advanced nations are also important customers for particular U.S. technologies, notably Germany (life science technologies and nuclear technologies) and Belgium (biotechnology), several of the newly industrialized and emerging Asian economies now rank among the largest consumers for U.S. technology products.

Top Nation Suppliers, by Technology Area

The United States is not only an important exporter of technologies to the world, but it is also a consumer of foreign-made technologies. Imported technologies enhance productivity of U.S. firms and workers, improve health care for U.S. residents, and offer U.S. consumers more choices.

The leading economies in Asia and Europe are important suppliers to the U.S. market in each of the 11 technology areas. (See figure 7-14.) Japan is a major supplier in five advanced technology categories, Germany in four. France, Canada, and the United Kingdom also supply a wide variety of technology products to the United States and are among the top three in several advanced technology areas.

A large volume of technology products comes from newly developed and developing Asian economies, in particular Malaysia, South Korea, Taiwan, and China. Growing technology product imports from these Asian economies and from other regions into one of the most demanding markets in the world indicate a further widening of technological capabilities globally.

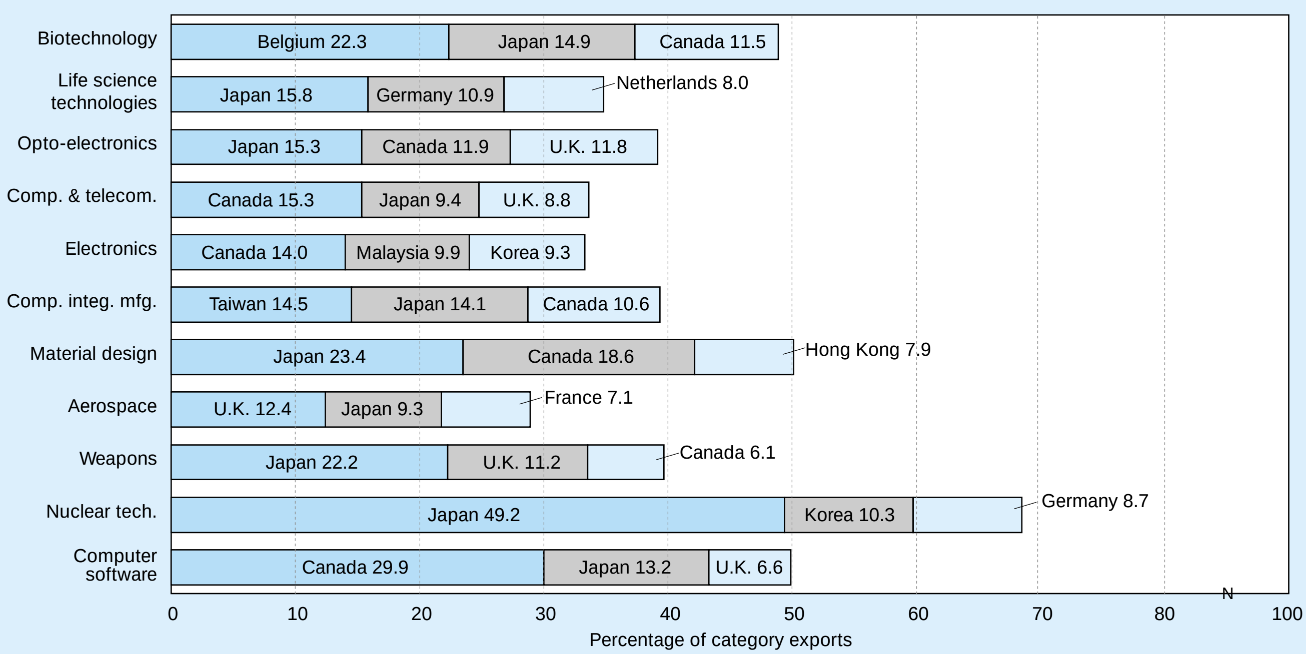
U.S. Royalties and Fees Generated from Trade in Intellectual Property

The United States has traditionally maintained a large surplus in international trade of intellectual property. Firms trade intellectual property when they license or franchise proprietary technologies, trademarks, and entertainment products to entities in other countries. These transactions generate revenues in the form of royalties and licensing fees.

U.S. Royalties and Fees from All Transactions

Total U.S. receipts from all trade in intellectual property reached $33.7 billion in 1997. This level extended a decade of steady increases that has resulted in a doubling of U.S. receipts since 1990. During the 1987–96 period, U.S. receipts were generally four to five times as large as U.S. payments to foreign firms for transactions involving intellectual property. The gap narrowed in 1997 as U.S. payments increased by 20

Figure 7-13.
Three largest export markets for U.S. technology products: 1998



See appendix table 7-6.

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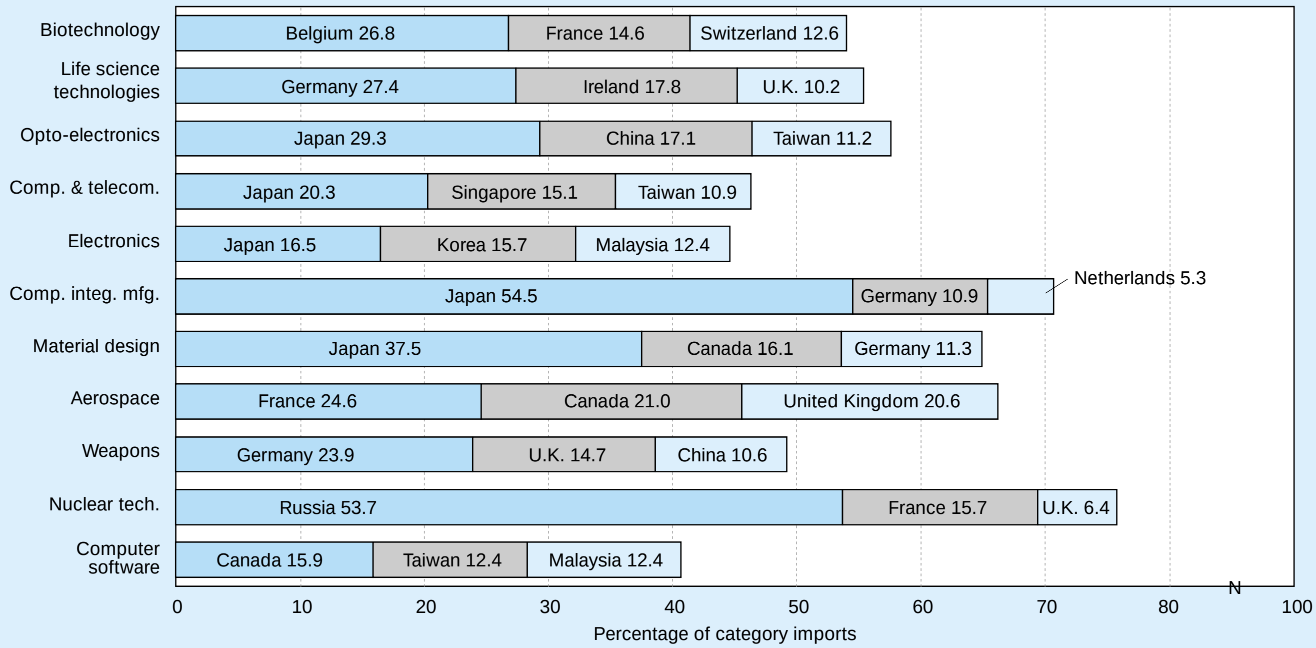
Figure 7-14.
Top three foreign suppliers of technology products to the United States: 1998



See appendix table 7-6. *Science & Engineering Indicators – 2000*

percent over the previous year and U.S. receipts rose less than 3 percent. Despite the much larger increase in payments, annual receipts from total U.S. trade in intellectual property in 1997 were still more than three and one-half times greater than payments. U.S. trade in intellectual property produced a surplus of $24.3 billion in 1997, down slightly from the nearly $25 billion surplus recorded a year earlier. Most (about 75 percent) of the transactions involved exchanges of intellectual property between U.S. firms and their foreign affiliates. (See figure 7-15.)[8]

Exchanges of intellectual property among affiliates have grown at about the same pace as those among unaffiliated firms. These trends suggest both a growing internationalization of U.S. business and a desire by U.S. firms to retain a high level of control on any intellectual property leased overseas.

U.S. Royalties and Fees from Trade in Technical Knowledge

Data on royalties and fees generated by trade in intellectual property can be further disaggregated to reveal U.S. trade in technical know-how. The following data describe transactions between unaffiliated firms where prices are set through a market-based negotiation. Therefore, they may reflect better the exchange of technical know-how and its market value at a given point in time than do data on exchanges among affiliated firms. When receipts (sales of technical know-how) consistently exceed payments (purchases), these data may indicate a comparative advantage in the creation of industrial technology. The record of resulting receipts and payments also provides an indicator of the production and diffusion of technical knowledge.

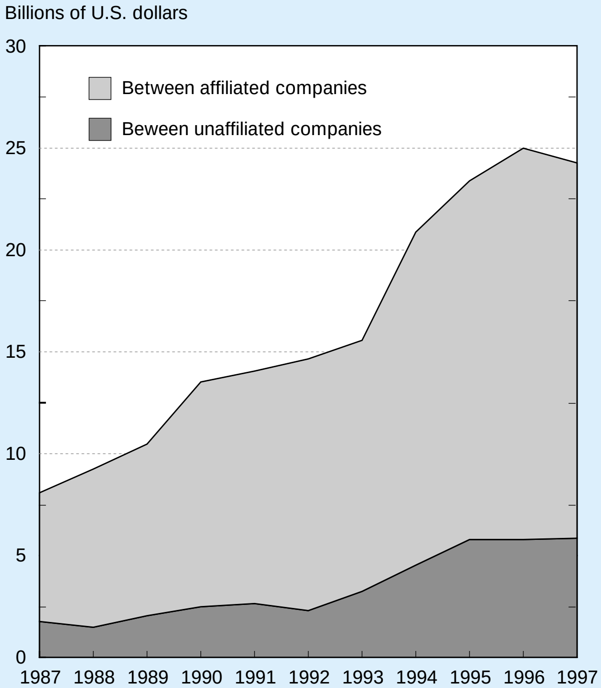
The United States is a net exporter of technology sold as intellectual property. During the past decade, royalties and fees received from foreign firms have been, on average, three times those paid out by U.S. firms to foreigners for access to their technology. U.S. receipts from such technology sales were about $3.3 billion in 1997, down slightly from $3.5 billion in 1996, but still nearly double that reported for 1987. (See figure 7-16 and appendix table 7-8.)

Japan is the largest consumer of U.S. technology sold as intellectual property. In 1997, Japan accounted for about 44 percent of all such receipts. The EU countries together represented about 22 percent. Another Asian country, South Korea, is the second largest consumer of U.S. technology sold as intellectual property, accounting for nearly 12 percent of U.S. receipts in 1997. South Korea has been a large consumer of U.S. technological know-how since 1988, when it accounted for 5.5 percent of U.S. receipts. South Korea's share rose to 10.7 percent in 1990, and reached its highest level, 17.3 percent, in 1995.

To a large extent, the U.S. surplus in the exchange of intellectual property is driven by trade with Asia. In 1997, U.S. receipts (exports) from technology licensing transactions were

[8]An affiliate refers to a business enterprise located in one country that is directly or indirectly owned or controlled by an entity of another country to the extent of 10 percent or more of its voting stock for an incorporated business or an equivalent interest for an unincorporated business.

Figure 7-15.
U.S. trade balance in intellectual property



See appendix table 7-7. *Science & Engineering Indicators – 2000*

nearly six times U.S. firm payments (imports) to Asia. As previously noted, Japan and South Korea were the biggest customers for U.S. technology sold as intellectual property. Together these countries accounted for more than 55 percent of total receipts in 1997.

The U.S. experience with Europe has been very different from that with Asia. Over the years, the balance of U.S. trade with Europe in intellectual property has bounced back and forth, showing either a small surplus or deficit until 1995. In 1995, United States–Europe trade produced a considerably larger surplus for the United States compared with earlier years, the result of a sharp decline in U.S. purchases of technical know-how from the smaller European countries that year. The following year also showed a large surplus, but this time it was driven by a jump in receipts from the larger European countries. The latest data (1997) show receipts from the larger European countries dropping back to pre-1996 levels, which caused a considerably smaller surplus from U.S. trade with Europe in intellectual property in 1997.

Foreign sources for U.S. firm purchases of technical know-how have changed somewhat over the years, with increasing amounts of coming from Japan. About one-fourth of 1997 U.S. payments for technology sold as intellectual property were made to Japanese firms. Europe still accounts for slightly more than 60 percent of the foreign technical know-how purchased by U.S. firms with France, Germany, and the United Kingdom being the principal European suppliers. Since 1992, however, Japan has been the single largest foreign supplier of technical know-how to U.S. firms.

International Trends in Industrial R&D

In high-wage countries like the United States, industries stay competitive in a global marketplace through innovation (Council on Competitiveness 1999). Innovation can lead to better production processes and better-performing products (for example, those that are more durable or more energy efficient). It can thereby provide the competitive advantage high-wage countries require when competing with low-wage countries.

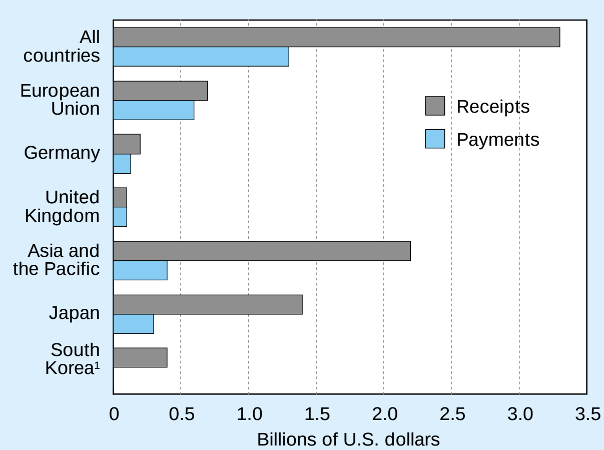
R&D activities serve as an incubator for the new ideas that can lead to new products, processes, and industries. Though they are not the only source of new innovations, R&D activities conducted in industry-run laboratories and facilities are associated with many of the important new ideas that have helped shape modern technology.

U.S. industries that traditionally conduct large amounts of R&D have met with greater success in foreign markets than less R&D-intensive industries and have been more supportive of higher wages for their employees.[9] Moreover, trends in industrial R&D performance serve as leading indicators of future technological performance. This section examines these R&D trends, focusing particularly on growth in industrial R&D activity in the top R&D-performing industries of the United States, Japan, and the European Union.[10]

[9]See the section, "U.S. Technology in the Marketplace," earlier in this chapter for a presentation of recent trends in U.S. competitiveness in foreign and domestic product markets.

[10] This section uses data from the OECD's Analytical Business Enterprise R&D database (Paris, April 1999) to examine trends in national industrial R&D performance. This database tracks all R&D expenditures (both defense- and nondefense-related) carried out in the industrial sector, regardless of funding source. For an examination of U.S. industrial R&D by funding source and type of research performed, see chapter 2 in this volume, "U.S. and International Research and Development: Funds and Alliances."

Figure 7-16.
U.S. royalties and fees generated from the exchange of industrial processes between unaffiliated companies: 1997



[1]Data withheld to avoid disclosing operations of individual companies.
See appendix table 7-8. *Science & Engineering Indicators – 2000*